

Contract Number

Nuvera Fuel Cells

US Coast Guard PEMFC Demonstration  
Final Report (DRAFT)

Proton Exchange Membrane (PEM) Fuel Cell Demonstration  
Of Domestically Produced PEM Fuel Cells in Military Facilities

US Army Corps of Engineers  
Engineer Research and Development Center  
Construction Engineering Research Laboratory  
Broad Agency Announcement **CERL-BAA-FY02**

USCG Aids to Navigation  
Bristol, RI

May 2005

## Executive Summary

Nuvera Fuel Cells installed two first-generation Avanti™ fuel cell power systems (FCPS) at the Aids to Navigation Team, U.S. Coast Guard site located in Bristol, Rhode Island. Avanti™ is Nuvera's second iteration of a distributed generation fuel cell system, designed to provide approximately 3.5 kW each of baseload electricity and heat. It is a residential type Proton Exchange Membrane fuel cell that uses Natural Gas as a fuel and runs in parallel with the electrical grid. It is rated for indoor operation and has cogeneration capabilities, although the heat generated has been predominantly radiated outdoors in this application.

The coastal installation site on Narragansett Bay provided an opportunity to operate these systems for the first time in a high salt air atmosphere with rapidly changing climatic conditions. With the cooperation of the USCG, this project has served as an excellent opportunity to evaluate fuel cell system performance and durability over an extended period in an uncontrolled environment.

Inquiries may be made to

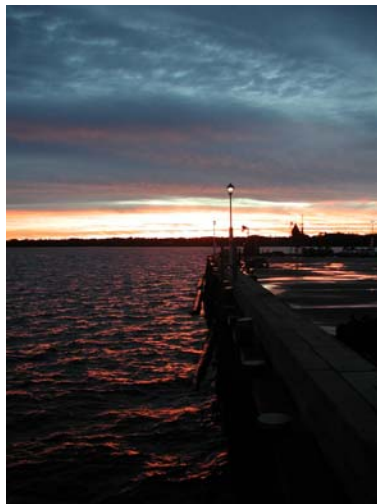
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## **Proposal – Proton Exchange Membrane (PEM) Fuel Cell Demonstration of Domestically Produced Residential PEM Fuel Cells in Military Facilities**

### **1.0     Descriptive Title**

DOD/USCG Avanti Fuel Cell System Demonstration: Bristol, RI

### **2.0     Name, Address and Related Company Information**

Nuvera Fuel Cells, Inc  
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617.245.7500

DUNS Number   04-344-8021  
CAGE Code       1YCK2  
TIN               04-3403793

Nuvera was formed in April 2000 through the merger of Epyx Corporation, a wholly owned subsidiary of Arthur D. Little, Inc. and De Nora Fuel Cells, a wholly owned subsidiary of Gruppo De Nora of Milan, Italy. The merger brought together 10 years of fuel processor technology from Epyx and 10 years of fuel cell stack technology from De Nora, as well as a wealth of knowledge, know-how, and expertise in chemical reactor design, electrochemistry, and system integration. Nuvera has offices in Cambridge, MA and Milan, Italy and is a privately held company with investors including Amerada Hess Petroleum, de Nora SpA and Renault.

### **3.0     Production Capability of the Manufacturer**

Nuvera is committed to developing commercially viable products utilizing their fuel processing capabilities in addition to dedicated hydrogen fuel cell systems for transportation and distributed generation applications.

Currently, field trials are being conducted on three continents with various corporate partners to evaluate systems in a variety of markets. The company is poised to take advantage of any emerging opportunities with a small on-site production facility capable of assembling hundreds of units per year in the near future. Nuvera has the intention of creating a larger manufacturing capability when it becomes prudent to do so for mass production of light-industrial hydrogen and fuel processing PEMFC distributed generation systems as well as hydrogen generation stations. It is the intention to continue supplying the automotive market with fuel cells, while licensing out the rights to manufacture fuel processing sub-systems for various transportation applications.

For more information, please contact Robert Derby at 617.245.7500  
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Foundation with Kurita Water Industries

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1-4-16, Kandenko, Tokiwa-Cho 1-Chome  
Urawa-Ku Saitama-shi  
330-0061 Japan

Tetsuo Motohashi  
048-834-7411

Installed Avanti Power Module outside of large dormitory, providing electricity and hot water  
under Japanese New Energy Foundation with Kurita Water Industries

CATERPILLAR  
Spring 2003  
Installed Model B ethanol reforming fuel cell system at Aventine site in Pekin, IL

MIT LINCOLN LABORATORIES  
Summer 2002  
Installed two H2PM Hydrogen Power Modules

VERIZON  
August 2002  
Installed Nuvera PowerStream Unit at distribution station in Woburn, MA

RWE  
Andreas Feldman  
October 2002  
Installed Nuvera PowerStream Unit at Mechernich Park, Germany

## 7.0 Host Facility Information



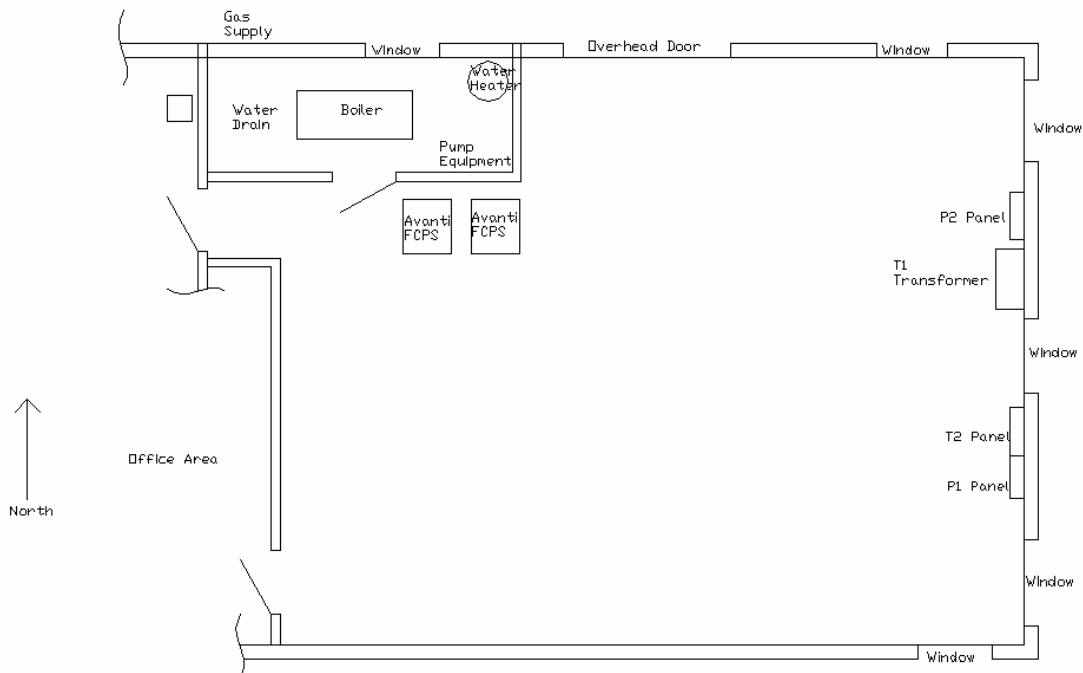
The U.S. Coast Guard, Aids to Navigation Team is located in Bristol, Rhode Island on a peninsula located between the Narragansett and Mount Hope Bays. Bristol is about 12 miles southeast of Providence and 12 miles north of Newport. This site maintains waterway navigation equipment and support of the heavily traveled waterways. The interior of a maintenance building that is used to repair equipment and fabricate metal and wooden components is the location of the installed Avanti™ units. Additionally, it houses an electronics repair facility and offices. The site is staffed 24 hours per day, 7 days per week with a night watch-person, but has core operation hours of 7am to 3:30pm.

The primary source of heating in the building is a gas fired forced hot water system located within the mechanical room. Several overhead radiator heating units with fans are located throughout the building and an electric water heater provides additional domestic hot water.

Natural Gas to the facility is provided by New England Gas (<http://www.negasco.com>). Electricity is provided by Narragansett Electric (<http://www.nationalgridus.com/narragansett>).

## 8.0 Fuel Cell Installation

Within the maintenance building, the section that houses the FCPS has an area of 938 sq ft and the layout is detailed in Figure 1. The Avanti™ units are placed along the north wall of the maintenance bay just outside the mechanical room due to the proximity of available utilities.



**Figure 1: Maintenance Shop Layout**

Once the decision where to install the systems was made and the routing of the utilities determined, the first steps of the physical installation were bringing the electrical tie-ins from the distribution panel P2 to the designated area by a licensed electrician. Auxiliary 110V power was then routed outside for the exhaust duct and radiator fans.

Licensed plumbers then tapped off the facilities' boiler gas supply, installed designated meters with digital outputs, extended 1½" lines around the mechanical room, through the wall and terminated at the intended site of the fuel cell systems.



**Figure 2: Installed Gas Meters**

Before the fuel cell systems arrived, the exhaust ducts were run through the mechanical room and out a portion of a pre-existing window where the vent fans were installed.

The Reverse Osmosis water filtration system was then mounted in the mechanical room, and the existing city water supply and drain lines were tapped into and routed through the dry-wall to the future system location.

A small area of ground was leveled on the North side of the building, and bricks were laid down to form the bases that the heat rejection boxes would sit upon. CPVC tubing was run from these cogeneration box pads through the exterior wall of the maintenance shop, up to the ceiling and then over the length of the room and down to the Avanti's.



**Figure 3: Cogen Boxes and Exhaust Fans**

The site Data Acquisition System and Data Collection Computer were then mounted on the near wall along with a small supply cabinet. One of the final steps taken before the actual fuel cell systems were installed was the routing of the cable internet by Cox Communications to enable remote data retrieval and system monitoring.

The fire department and electric company were notified of the intentions to operate and connect to the grid, and all basic requirements were satisfied (although no specific permit was required).

The overall effort to prepare the facilities for the installation of the fuel cell power systems spanned ten working days. This included eight hours of labor from a licensed plumber, 16 hours of a licensed electrician and the better part of two weeks time of two engineers designing the layout, purchasing materials and physically setting up the equipment to provide the necessary site utilities and data acquisition systems.



**Figure 4: Crated System Arrival and Positioning**

The first of the Avanti units was installed November 11<sup>th</sup>, 2003. Once the system was thoroughly inspected, power was fed to the inverter and the various pumps, blowers, solenoid valves, etc. were actuated to ensure functionality. The cogeneration lines were filled with fluid, leaks resolved and pumps primed. On November 13<sup>th</sup>, the first light-off ensued.



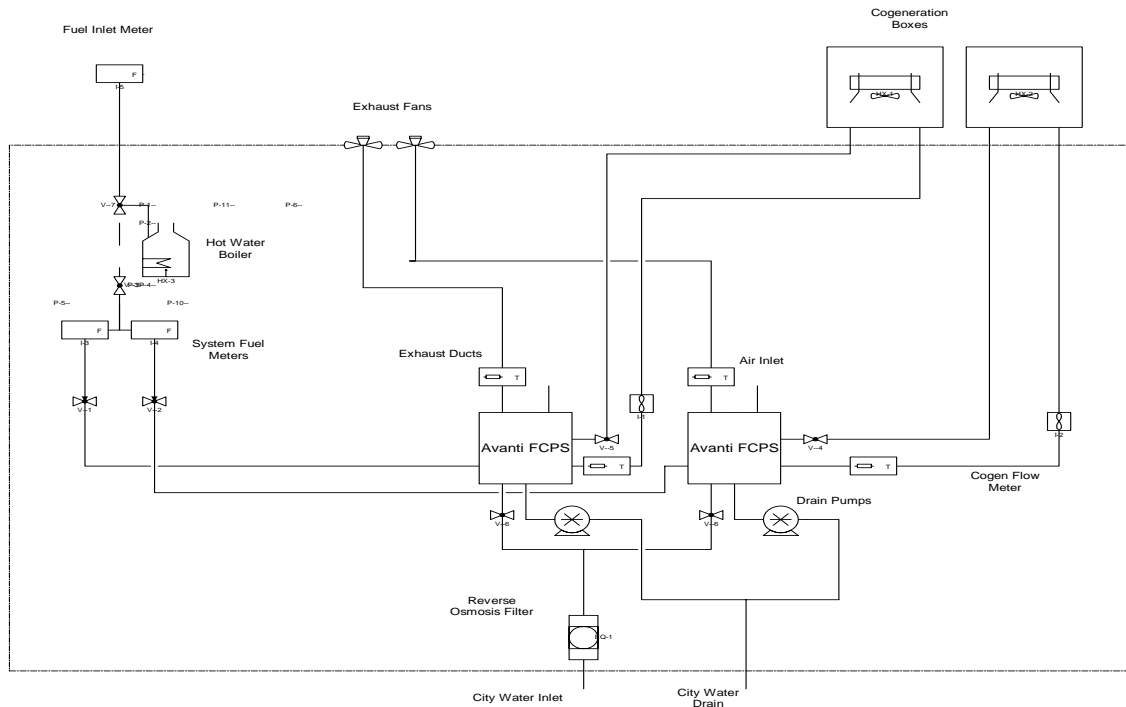
**Figure 5: Utility Connections and Installed Units**

The following Table contains historical data of the electrical loads of the maintenance building at the Aids to Navigation Coast Guard facility for the year 2003. From this it can be seen that two Avanti fuel cell power modules operating nominally at 3.5kW would not normally be able to fully supplant the grid in this application, particularly in the winter months as the demand is too high. However, during off-peak and summer operation periods there would often be instances of excess capacity in which case electricity was fed back onto the grid from the fuel cells.

| Bill Date  | kWh Use | Net Bill   | Avg.<br>Cost/kWh | # of day | Avg. Use/ Day |
|------------|---------|------------|------------------|----------|---------------|
| 3/29/2002  | 8000    | \$738.99   | \$0.09           | 28       | 285.7         |
| 4/29/2002  | 7800    | \$729.27   | \$0.09           | 31       | 251.6         |
| 5/30/2002  | 8100    | \$750.57   | \$0.09           | 32       | 253.1         |
| 6/28/2002  | 7100    | \$679.52   | \$0.10           | 28       | 253.6         |
| 7/29/2002  | 3600    | \$430.84   | \$0.12           | 30       | 120           |
| 8/26/2002  | 5800    | \$565.61   | \$0.10           | 29       | 200           |
| 9/25/2002  | 4600    | \$480.34   | \$0.10           | 32       | 143.8         |
| 10/25/2002 | 5800    | \$565.61   | \$0.10           | 28       | 207.1         |
| 11/25/2002 | 7300    | \$672.20   | \$0.09           | 30       | 243.3         |
| 12/31/2002 | 9700    | \$850.79   | \$0.09           | 36       | 269.4         |
| 1/29/2003  | 12100   | \$1,042.47 | \$0.09           | 31       | 390.3         |
| 2/27/2003  | 11600   | \$1,012.21 | \$0.09           | 29       | 400           |

**Table 1: Site electric billing information**

During the period of operation, gas usage for the building was expected to increase as the space heating was still required in the colder months, and additional natural gas was necessary for the operation of the Fuel Cell Power Systems. At full power, the FCPS operates at approximately 12kW thermal input or 43 scfh. At this rate and with the current utility costs, an expected economic detriment was achieved. An alteration in the setup to utilize the Avanti cogeneration capabilities for providing space heating and domestic hot water would have swung the pendulum in the other direction, but the level of complexity was deemed too costly for this one year demonstration.



**Figure 6: System Interface Schematic**

## 9.0 Electrical System

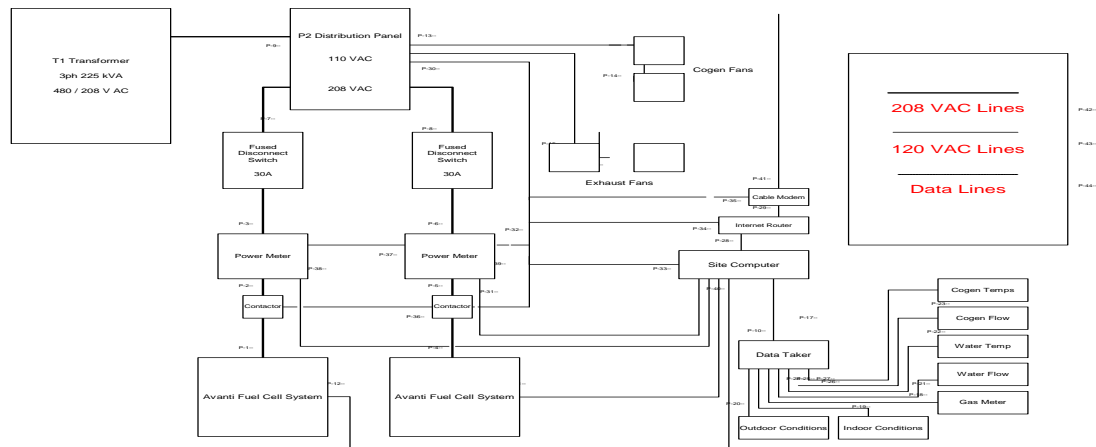
Inside of the maintenance shop there are two transformers, T1 and T2, and two distribution panels marked as P1 and P2 - as seen again in Figure 1. T1 is a 3 phase, 225 KVA transformer with a 480V / 270A high-voltage side and 208V with four 120V taps rated at 625A total - which feeds the P2 distribution panel with a 225A main breaker switch. T2 is a transformer that feeds P1 and a second sub-panel that is incorporated into T2. This sub-panel is rated at 440V and 600A, contains 5 breakers - one connected to a welder and the other 4 supplying power to the ship power supplies located on the dock. The headquarter building that is located on-site is supplied by a second electrical service with a stand-alone meter.

The Avanti Fuel Cell Power Module is designed to operate as a grid parallel system. It is dependent upon the electricity regularly fed into the facility to power it during startup, standby and shutdown modes; typically consuming 250-500W of power that has been converted to DC current by the integrated power inverter during such operation. These systems are not capable of providing backup power in the event of a grid failure as a result of this configuration.

When generating, the fuel cell creates electricity on an 80V DC internal bus that first provides power for the auxiliary components. The remainder is then fed to the same inverter which then feeds 208V AC back to the electrical grid. The output is generally between 10 and 20A on two phases (AB on Alpha 1 and BC on Alpha 3), capable of feeding 2-4 kW to the facility. Whatever is not consumed by the wood-shop, machine-shop, maintenance garage, building offices or external boat utilities during off-peak hours are sent back to the power grid. On-site net-metering effectively spins the kWh meter readings backward, thus increasing potential electric bill savings.

Physically, new circuit breakers were installed in the existing 117/208 VAC distribution panel (P2) on each phase as depicted in Figure 7. From there, lines were run up along the ceiling across the shop into the system vicinity where they terminate in a fused disconnect for each system.

Power can be shut off and locked out independently for service work. From there the lines pass through the electronic power meters that monitor the voltage, current, frequency and harmonics of the electricity being generated by (or fed to) the inverter. The meters will also calculate power output, power factor and total energy produced, and will open a contactor to disconnect the fuel cell system from the grid when an alarm is triggered by out of range voltage or frequency as required by the Narragansett Electric Power Generation Interconnect guidelines. This safety measure is replicated in the inverter software, and either cutout will occur regardless of whether the fault is on the fuel cell side or an electric grid anomaly.



**Figure 7: Electrical System Diagram**

## 10.0 Thermal Recovery System

The heating system for the maintenance building is located in the mechanical room and is described as forced hot water. The system uses a natural gas fired boiler connected to a city supply outside of the north wall.

The setup for heat dissipation from the Avanti units is a radiator system installed outside the north face of the maintenance building and is independent of the forced hot water system. These Cogen Boxes are placed at ground level, and consist of a typical automotive style radiator with fans pulling air through a perforated sheet-metal cabinet, which are actuated by temperature switches. The Cogen fluid is a mix of water and propylene glycol, and runs through CPVC piping elevated 10 feet in the air along the ceiling from the Avanti systems before exiting through the wall and falling down to the Cogen boxes. Here, the accumulated heat gathered from the fuel cell system is rejected to the atmosphere before returning significantly cooler to the systems. Ideally, the radiators would be placed on an elevated frame or the roof of the building at a height that would aid in the bleeding of air from the lines of the closed system. This would better support filling and topping off the fluid level, but the infrastructure modifications again were resource limited due to the temporary nature of the demonstration. The existing setup is functional once filled, although not completely user-friendly.

There was a potential to install a radiator system inside of the building for supplemental heating of the maintenance bay. Since each room in the building has its own heat exchanger and control system for the forced hot water system, it would have been possible to install radiators in parallel without affecting the current heating system. The heat dissipation from the Nuvera FCPS is rated at 5kW for each unit, and would be quite effective at heating the large maintenance area. This would be welcomed in the winter months as the space can be extremely cold with the slab concrete floors and frequently wide-open overhead door. A simple control scheme could have

been used to switch over to the outdoor radiators when heat isn't required - however the system was never upgraded due to resource constraints.

The installation setup was not instrumented to monitor the rejected heat at the radiator, but the flow-rate was recorded as well as the coolant temperatures at the Avanti inlet and outlet interfaces. A typical measured state of 65C outlet with a 30C return at a flowrate of 2.3 lpm with a 50/50 mix of glycol and water (that can be varied seasonally, but using an approximate heat capacity of 3.4 kJ/kg\*K) yields 4.6 kW of heat available.

## 11.0 Data Acquisition System

The Avanti Fuel Cell Power System contains a series of five embedded control modules centered around an ECU that serves as the brains of the system. It operates on a CAN protocol bus to communicate with the Burner Management Module and the Inverter; and external computers can tap into this feed to monitor the system performance and archive the CAN bus data on a dedicated site PC. Recorded parameters include various fuel processor and fuel cell temperatures, digital and analog input and output control signals for the balance of plant components and electrical output as reported by the inverter.

To measure the environmental conditions at the Coast Guard site, a DataTaker brand system was installed to monitor and store a number of parameters and calculate certain values - including:

- Natural Gas Volume – as measured by the installed gas meters with digital output
- City Water Inlet temperature
- City Water Inlet flow
- Water Drain volume
- Cogen Fluid Inlet/Outlet temperature
- Cogen Fluid flow
- Exhaust Temperature
- Outdoor Temperature
- Outdoor Relative Humidity
- Ambient Pressure
- Indoor Temperature
- Indoor Relative Humidity

This data was stored locally in the DataTaker hard drive, and then unloaded daily to the site PC.

Finally, electronic Power Meters were installed to measure and calculate the electricity either consumed or delivered by the fuel cell systems to the grid. They do not have any data storage capacity, but communicate continuously via RS485/232 to the site computer, where the individual phase voltage and current are displayed as well as the frequency and power output of each system on another LabView window. This information was then also logged on the PC.

A cable modem had been installed at the site to connect the site computer to the internet through a router. The PC could then be accessed and viewed remotely, and Nuvera would also download the necessary data off of that machine and archive it daily on a server in Cambridge.

A change from the initial data collection plan had been a switch from one site computer to two. With all the applications running simultaneously and two separate CAN bus streams from each system feeding into one computer, the remote accessing of the one computer was overloading it regularly.

## 12.0 Fuel Supply System

The Natural Gas supply line that feeds the boiler in the mechanical room was tapped off of and split into two trunks with a main shutoff valve for the two systems. Designated volumetric gas meters with digital outputs were mounted to the wall inside the mechanical room, and one inch pipes were run up around the door frame and down and out through the interior wall where manual shutoff valves are located for each individual system. Stainless flex-lines were then run from the wall taps to the back of the fuel cell systems, with yet another manual shutoff valve at the fuel inlet port.

When an internal solenoid valve is opened, the fuel then passes through two desulfurizer canisters before reaching the compressor that delivers the fuel to the reformer. This system is robust enough to handle changes in line pressure, although variations in thermal heating value due to extreme environmental conditions and heavy area demand have created some issues.

### 13.0 Program Costs

The majority of the incurred charges associated with the installation of the two Avanti fuel cell power modules at the Coast Guard site in Bristol, RI involve labor and associated personnel costs. In future occasions, engineers will be able to design the layout, purchasing departments will be able to supply all the required materials and technicians trained in system installation will be able to perform the required work in a much more cost and time-effective manner than this iteration. Ideally, laborers would also be licensed to perform the electrical and natural gas services in the municipality that the systems are being installed at, further reducing the labor charges billed to outside contractors.

The basic materials required to interconnect the fuel cell systems to the utilities were quite simple and fairly inexpensive. The data collection systems significantly boosted the as-installed cost. When the fuel cell power modules eventually mature as product and such intensive monitoring becomes superfluous, the capital investment in PC's, data acquisition devices and required components such as flowmeters become dispensable – and thus eliminating a large percentage of the installation costs.

The following is a rough breakdown of the related costs incurred:

|   |                 |
|---|-----------------|
| Nuvera Engineers Based on two full weeks of labor performed |                 |
| 160 hrs at \$100/hr   | \$16,000        |
| Miles and expenses  | \$1,800         |
| Licensed Plumber Services – labor and materials             |                 |
| 2 plumbers x 4hrs   | \$825           |
| Licensed Electrician Services                               |                 |
| 16 hrs at \$75/hr   | \$1200          |
| Cable internet installation                                 |                 |
| Service Fee   | \$80            |
| Shipping  |                 |
| Crates (2 avanti, 2 inverter)                               | \$900           |
| Shipper (2 trips)   | \$850           |
| General Installation Materials                              | \$1200          |
| See below for full list                                     |                 |
| Data Acquisition Components                                 | \$8500          |
| See below for full list                                     |                 |
| <b>Total</b>  | <b>\$31,355</b> |

#### 14.0 Milestones/Improvements

Despite the fact that after one year of operation, the Avanti systems were unable to sustain long periods of high availability as required by this specific contract, the demonstration does represent the high-water mark at Nuvera for a non-lab based fuel-processing fuel cell power system in terms of total run time. Other year-long contracts have focused on maximizing power output and efficiency in addition to system reliability.

The site preparation work was completed by early November 2003, and the first fuel cell system installed on November 11<sup>th</sup>. This system was then operated to ensure that the facilities were sufficient and the data acquisition functional. There was a delay on the shipment of the second unit until the end of the year, and it was installed and first run on January 5<sup>th</sup>, 2004.

The next phase of operation involved running the systems manually to determine the proper set-points following the on-site fuel calibrations. The Heat Cogeneration System (actually heat rejection in this application) also had to be fine-tuned with the proper flow restriction. Making this particularly difficult was the brutally cold January weather the prior year in New England. With temperatures regularly below zero F for a two week period coupled with the biting wind coming off the bay at the Coast Guard facility, the return temperatures from the radiator boxes located outside the building were much lower than anything these systems had ever experienced. Compounding the problems were the fact that this generation of Avanti fuel cell system was designed for indoor operation (although others have been retrofitted for outdoor use), and in the Maintenance Building – the overhead door regularly had to be left open for the majority of the day. Without proper insulation for this cold of an environment, this would significantly chill the steam loop and prevent optimal fuel processing. Also, during the most severe periods we experienced a few drastic pressure drops in the natural gas supply due to the overtaxed heating requirements in the area that caused some problems. These conditions made it difficult to commission the systems, but at least one weather extreme was experienced in the early stages of operation rather than further along in the performance period.

Once all of these issues were resolved, new software with the proper set-points was loaded onto the ECU control module. The automated systems were then allowed to run for the next couple of weeks to resolve any infant mortality issues with any of the components. Once all were satisfied with the operation, it was decided to begin the performance period mid-February for both installed systems.

#### 15.0 Decommissioning/Removal/Site Restoration

Following the completion of the performance period, the systems were officially decommissioned after receiving approval to do so. The Avanti units were drained of all fluids and the fuels were purged with shop air after sitting idled for over one month. The utilities and data collection equipment were disconnected and dismantled after retrieving necessary data. The systems were removed with the small Avanti custom-built dolly and then lifted onto a rented box-truck with the Coast Guards' fork lift. One engineer was able to remove all the equipment and repair the drywall over the course of three days. An electrician was required to restore the electrical panel to its pre-Avanti state, and a contractor was needed to repair a laminate-wooden office floor in the building that had sustained slight water damage during the year.

## 16.0 Additional Research/Analysis

A number of small studies were conducted to investigate the various new failure modes experienced at the Coast Guard installation. Although it was not possible to implement a permanent fix on this generation system, the on-site testing done on a one-pass steam system to increase steam pump life and the duration between filter changes has had a major impact on the development of the current generation system now undergoing evaluation. Particularly in reference to problems generated by sub-par air quality, water quality and electric grid power quality; data analysis is still being conducted to isolate and quantify the effects of each variable on specific sub-systems.

## 17.0 Conclusions/Summary

After operating the two Avanti Fuel Cell Power Modules at the USCG site in Bristol, RI for over a year, it was apparent that the systems would not be able to achieve the 90% availability target over a 12 month period as outlined in the contract with DOD CERL. Although they did show the ability to attain this performance figure over month-long intervals, it was difficult to do so in successive periods for a number of reasons.

Aside from the deficiencies of the Avanti itself, there were a number of unexpected external factors that limited availability. Restricted personnel hours at the Coast Guard facility prevented night-time maintenance. It was nothing too extreme, but if a service call had to be cut short before the system was once again operational, it was likely to be down an additional 12 hours – which can be difficult time to make up.

The electrical grid in the area was built on quite an old infrastructure, and suffered many disturbances that would shut the systems down as dictated in local interconnect standards for power generators. As expected the occasional brown-out would cause an outage in a grid-parallel system, but particularly in the summer months the site would experience a loss of grid stiffness and voltage fluctuations - often low on hot/humid days with heavy demand. There were also localized electrical disturbances as a plasma cutter used in the Maintenance building would create an electrical interference whenever used and trip the 110Vac circuit powering the system's electrical meter - despite being fed through different distribution panels. As described earlier, these meters contain alarm states that disconnect the fuel cell inverter from the grid in the case of any anomaly. Unfortunately, this disturbance was apparently at such a high frequency that it could not be measured or captured without sophisticated equipment hooked up. This was also the case less often when a high-frequency welding machine was used to work on aluminum.

The Maintenance facility proved to be a difficult site to work in for other reasons as well. Frequently, the overhead door had to remain open to facilitate the work of the Coast Guard – which became a problem when it was very cold. Although the same type of systems have been installed and operated outdoors for other contracts, they were fitted with an extra weatherproof enclosure. The Avanti that is designed for indoor operation is susceptible to cold ambient temperatures that can chill the steam lines and adversely affect heat transfer between vessels.

Airborne pollutants and particulates also had a detrimental affect on the systems. In two different occasions, the cabinet inlet air filter had become impassably clogged with grinding residue, resulting in a cathode air blower over-temperature once, and a starving of air for the burner air blower the other. Despite having a cathode air inlet chemical filter installed on each system, on two other occasions paint overspray was noted to have permeated through to the stack and immediately drop the voltage on each system between 5 and 10 Volts DC. It had been hoped that the proximity of the site to the salt water might provide some performance data pertaining to the degradation of the stack in a saline environment, but the presence of welding

and plasma cutter fumes, diesel and gas powered fork truck and snow blower exhaust, and volatile organic compounds released from the industrial parts cleaner solvents most likely reduced the salt air to a minor and indistinguishable effect on the fuel cell performance.

However, it is also suspected that poor water quality at the site contributed to some premature fouling of RO Beds, DI Beds, steam filter clogging and steam line calcification. This led to polarized water in the stack earlier than anticipated given the DI Bed expected lifetime and thus bipolar plate corrosion, as well as frequent steam system failures. The results of water quality tests are not back as of this writing from the Clean Harbors Lab, at which point the presence of excessive contaminants can be confirmed or disproved.

That said, the shortcomings of this first generation Avanti system were clearly flushed out in the course of this demonstration. Aside from the resultant degradation of the fuel cell and fuel processor catalysts due to the frequent hard shutdowns and contaminants, many areas of potential improvement were targeted based on the data and feedback from these two systems and resolved in the third generation Avanti currently undergoing trials. These major issues include the following:

Controls Strategy

Fuel and air flow sensors to accurately measure input – no site specific calibration required

Active H<sub>2</sub> Generation and power output control

calculated utilization and efficiency setpoints

Stack Architecture

Direct Water Injection – better cooling flow distribution and membrane moisturizing resulting in fewer damaged cell pairs, less corrosion potential

Fuel Processor Assembly

Revised burner design – even flame distribution results in less thermal stress and heat loss

Steam System

Single pass water flow – elongated steam filter and water pump life, fewer steam system failures prevents coking and catalyst deactivation

Inverter

New supplier with more robust design – better able to handle grid disturbances

Cathode Blower

Higher over-temp limit

Heat Cogeneration system

Air Bleeding reservoir, cold weather control strategy with corrosion/calcification resistant fluid

Cathode Air Inlet

Chemical filter in poor air quality environment

System Enclosure

Insulated, heated and ventilated to operate indoors or outdoors in temperate climate

Based on these findings alone, the Residential PEM Fuel Cell Demonstration Program has proven to be invaluable to the Nuvera team. Despite the inability to achieve the 90% availability figure - the experience gained installing, operating, monitoring, troubleshooting and servicing fuel cell power systems in a real world environment has made this an overwhelming success for Nuvera, and we look forward to working with DOD / CERL again in the future.

## Appendix

| Month  | Run Time | Availability | Energy Produced | Average Output | Capacity Factor | Electrical Efficiency | Thermal Efficiency | Overall Efficiency |
|--------|----------|--------------|-----------------|----------------|-----------------|-----------------------|--------------------|--------------------|
|        | (Hours)  | (%)          | (kWe-hrs)       | (kW)           | (%)             | (%)                   | (%)                | (%)                |
| Feb-04 | 370      | 86%          | 1162            | 3.14           | 79.1%           | 25.8%                 | 59.1%              | 84.9%              |
| Mar-04 | 732      | 98%          | 2260            | 3.09           | 89.3%           | 25.3%                 | 53.1%              | 78.4%              |
| Apr-04 | 314      | 44%          | 926             | 2.95           | 37.8%           | 23.6%                 | 32.8%              | 56.4%              |
| May-04 | 323      | 43%          | 795             | 2.46           | 31.4%           | 21.1%                 | 33.8%              | 54.9%              |
| Jun-04 | 496      | 69%          | 1288            | 2.60           | 52.6%           | 26.0%                 | 29.1%              | 55.1%              |
| Jul-04 | 293      | 39%          | 770             | 2.63           | 30.4%           | 26.1%                 | 30.8%              | 56.9%              |
| Aug-04 | 476      | 64%          | 1337            | 2.81           | 52.9%           | 25.8%                 | 27.3%              | 53.1%              |
| Sep-04 | 705      | 98%          | 1915            | 2.72           | 78.2%           | 24.4%                 | 28.5%              | 52.9%              |
| Oct-04 | 467      | 63%          | 1105            | 2.37           | 43.7%           | 19.9%                 | 33.3%              | 53.3%              |
| Nov-04 | 497      | 69%          | 1103            | 2.22           | 45.1%           | 22.9%                 | 30.5%              | 53.4%              |
| Dec-04 | 373      | 50%          | 554             | 1.49           | 21.9%           | 16.7%                 | 35.0%              | 51.7%              |
| Jan-05 | 278      | 37%          | 365             | 1.31           | 14.4%           | 15.8%                 | 28.8%              | 44.6%              |
| Feb-05 | 599      | 89%          | 833             | 1.39           | 36.5%           | 18.5%                 | 34.5%              | 53.0%              |

**Alpha 1 Avanti**

| Month  | Run Time | Availability | Energy Produced | Average Output | Capacity Factor | Electrical Efficiency | Thermal Efficiency | Overall Efficiency |
|--------|----------|--------------|-----------------|----------------|-----------------|-----------------------|--------------------|--------------------|
|        | (Hours)  | (%)          | (kWe-hrs)       | (kW)           | (%)             | (%)                   | (%)                | (%)                |
| Feb-04 | 207      | 75.3%        | 654             | 3.16           | 74.3%           | 25.6%                 | 53.7%              | 79.3%              |
| Mar-04 | 656      | 88.2%        | 1764            | 2.69           | 74.1%           | 22.6%                 | 53.7%              | 76.4%              |
| Apr-04 | 301      | 41.8%        | 739             | 2.46           | 32.1%           | 19.1%                 | 36.1%              | 55.2%              |
| May-04 | 628      | 84.4%        | 1856            | 2.96           | 78.0%           | 26.5%                 | 31.0%              | 57.5%              |
| Jun-04 | 285      | 39.6%        | 763             | 2.68           | 33.1%           | 27.6%                 | 31.3%              | 58.9%              |
| Jul-04 | 238      | 32.0%        | 480             | 2.02           | 20.2%           | 21.1%                 | 46.9%              | 68.0%              |
| Aug-04 | 506      | 67.9%        | 966             | 1.91           | 40.6%           | 18.5%                 | 41.4%              | 59.8%              |
| Sep-04 | 490      | 68.1%        | 1102            | 2.25           | 47.8%           | 22.3%                 | 46.2%              | 68.5%              |
| Oct-04 | 632      | 84.9%        | 1094            | 1.73           | 46.0%           | 17.3%                 | 53.8%              | 71.1%              |
| Nov-04 | 605      | 84.0%        | 1088            | 1.80           | 47.2%           | 18.6%                 | 33.5%              | 52.0%              |
| Dec-04 | 397      | 53.4%        | 707             | 1.78           | 29.7%           | 20.1%                 | 36.5%              | 56.6%              |
| Jan-05 | 428      | 57.5%        | 568             | 1.33           | 23.9%           | 17.3%                 | 33.8%              | 51.1%              |
| Feb-05 | 115      | 17.1%        | 185             | 1.61           | 8.6%            | 21.0%                 | 28.2%              | 49.2%              |

**Alpha 3 Avanti**